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Fluoridation of water supplies and cancer mortality
II: Mortality trends after fluoridation

PAULA COOK-MOZAFFARI
From the Department of Community Medicine and General Practice (MRC External Staff), University of Oxford

RICHARD DOLL
From the ICRF Cancer Epidemiology and Clinical Trials Unit, University of Oxford

In the past two years much publicity has been given to Burk's[1-3] claim that the mortality from cancer in Birmingham increased sharply following fluoridation of the water supply in 1964 and, specifically, that it increased more sharply than in other British towns. This claim is not supported by detailed examination of age-standardised mortality rates in England and Wales[4] and we have, therefore, re-examined the data to see what led Burk to his conclusion.

Within Britain, it is only in Birmingham that water supplies have been fluoridated on sufficiently large a scale and for a long enough period of time to permit analysis of trends in mortality after fluoridation. The mortality experience there can be interpreted sensibly only against the background of observations that have been made in other parts of the world, where water supplies have also been fluoridated. We have, therefore, supplemented our examination of Burk's data with a review of the trends observed elsewhere.

BURK'S DATA

Burk[1 2] obtained from the Office of Population Censuses and Surveys (OPCS) the number of cancer deaths and the estimated populations for the cities of Birmingham and Manchester for each year from 1953 to 1977. From these data he calculated crude death rates and presented graphs and regression analyses derived from these to illustrate the 'cancer mortality trends'. This material was widely circulated in an 'open letter'[1] and details of his calculations were set out in another letter sent to an official at the Department of Health and Social Security, which has also been widely circulated in Britain and the USA.[2] From the tabulations in this document it seems clear that, with the reorganisation of local authority areas in 1974, a confusion had arisen over the precise extent of the urban areas which were being compared. A table giving the year-by-year crude death rates from 1953 to 1977 had titles indicating that the data were for 'Birmingham County Borough plus Sutton Coldfield Municipal Borough' and for 'Manchester County Borough plus a part of Bucklow Rural District', that is, the metropolitan districts as they were constituted after the 1974 reorganisation. For the years before 1974, however, the figures given in the body of the table did not include these additions but are those that were published for the county boroughs of Birmingham and Manchester, both for populations and for cancer deaths (Registrar General's *Statistical Review of England and Wales* for the years 1953 to 1973). For most years the total of all cancer deaths has to be summed from the listing of individual sites and types given in these volumes. There are minor differences between our summations and those given by Burk, which could be errors of addition (Table 1). From 1974 to 1977, the figures that he gave for cancer deaths were the published figures for the new Birmingham and Manchester metropolitan districts, including Sutton Coldfield and a part of Bucklow rural district respectively, but the populations were not; those for Birmingham had been reduced by about 8·0% and those for Manchester had been increased by about 1·6% (Table 1). From the population estimates published for 1973 and provided for the present analyses by the OPCS for 1974, it appears that, during the year of the change of status from county borough to metropolitan district, the population of Birmingham increased by 6·2% and that of Manchester decreased by 3·1% (despite an increase of 0·02% by the addition of a part of Bucklow rural district).* Presumably, therefore, Burk's adjustment for Birmingham was an attempt to make the post-1974 populations comparable with those of the earlier period, and was made under the mistaken impression that the cancer deaths which he was given

*Calculations by the OPCS[5] showed that, had the rate of growth since the 1971 census been the same for each local authority area, the former Sutton Coldfield metropolitan borough would make up 7·6% of the new Birmingham metropolitan district created in 1974 and the part of Bucklow rural district added to Manchester would make up 0·02% of the new metropolitan district.

Table 1 *Crude cancer death rates for Birmingham and Manchester for the period 1959 to 1977*

	Burk's data for: 'Birmingham CB and Sutton Coldfield MB'*			*Corrected data[a] for: Birmingham CB (MD after 1974)*			*Burk's* data for: 'Manchester CB and a part of Bucklow RD'*			*Corrected data[a] for: Manchester CB (MD after 1974)*		
	Cancer deaths	Estimated population (in 100 000s)	Crude death rate per 100 000	Cancer deaths	Estimated population (in 100 000s)[b]	Crude death rate per 100 000	Cancer deaths	Estimated population (in 100 000s)	Crude death rate per 100 000	Cancer deaths	Estimated population (in 100 000s)[b]	Crude death rate per 100 000
1959	2389	10·92	218·9	2390	10·92	219·0	1531	6·723	227·7	1531	6·723	227·7
1960	2290	10·93	209·5	2289	10·93	209·4	1634	6·656	244·0	1624	6·656	244·0
1961	2355	11·10	212·1	2300	11·10	207·2	1602	6·603	242·6	1602	6·603	242·6
1962	2355	11·15	204·6	2355	11·15	211·2	1597	6·592	242·6	1597	6·592	242·3
1963	2393	11·16	214·5	2393	11·16	214·5	1619	6·547	247·3	1619	6·547	247·3
1964	2296	11·06	207·6	2296	11·06	207·6	1559	6·445	241·8	1559	6·445	241·9
1965	2437	11·03	221·0	2437	11·03	221·0	1618	6·384	253·4	1618	6·384	253·5
1966	2431	11·03	220·4	2432	11·03	220·8	1555	6·253	248·7	1555	6·253	248·7
1967	2515	11·03	228·1	2515	11·02	228·2	1604	6·165	260·2	1604	6·165	260·2
1968	2605	10·75	242·3	2607	10·75	242·5	1584	6·028	262·8	1585	6·028	262·9
1969	2577	10·86	237·2	2597	10·86	237·4	1544	5·938	260·0	1544	5·938	260·0
1970	2537	10·84	234·0	2537	10·84	234·0	1557	5·900	263·81	1557	5·900	263·9
1971	2513	10·13	248·0	2513	10·13	248·0	1540	5·424	283·9	1540	5·424	283·9
1972	2474	10·07	245·7	2474	10·07	245·7	1520	5·313	286·3	1520	5·313	286·1
1973	2676	10·04	266·5	2676	10·04	266·5	1537	5·306	289·7	1537	5·306	289·7
1974	2841	9·96	285·3	2841	10·81	262·8	1489	5·195	286·6	1489	5·114	291·2
1975	2719	9·83	276·5	2719	10·69	254·4	1498	5·102	292·0	1490	5·021	296·8
1976	2844	9·73	292·4	2844	10·58	268·9	1516	5·053	300·0	1516	4·972	304·9
1977	2795	9·66	289·3	2795	10·50	266·2	1478	4·997	295·8	1478	4·916	300·7

*Burk, 1979[2]

[a]The crude death rates for Birmingham and Manchester CBs and MDs were calculated using the full population estimates for each year and not the rounded figures presented here. This accounts for minor differences between these rates and those calculated by Burk when the figures for cancer deaths and population estimates are the same.

[b]The corrected populations shown here are those from the Registrar General's *Statistical Reviews* (as used also by Burk) for the years previous to 1974 and are not the OPCS revised populations used as a basis for the calculations illustrated in the Figure.

for 1974 to 1977 were for the areas as they were defined before 1974. However, the logic of the adjustment for Manchester is difficult to follow, since he increased the population by 1·6% instead of trivially decreasing it to allow for the addition of a part of Bucklow rural district. The effect of adjusting the populations, but not the number of deaths, and of adjusting the Manchester population in the wrong direction, is to exaggerate the rate of increase in the crude cancer death rate in Birmingham compared with that of Manchester. Recalculation of Burk's analyses gives regression slopes which indicate an almost identical rate of change in the crude cancer death rates in Birmingham and Manchester between 1965 and 1977.

After these errors had been corrected, Burk presented the data in another form[3] at the Fourth International Symposium on the Prevention of Cancer* in which regression analyses of crude cancer death rates for periods before and after 1964 were compared between Birmingham and a group of other English cities (those examined by Cook-Mozaffari, Bulusu, and Doll,[4] with the addition of Bradford, Newcastle upon Tyne and Coventry). The index of changing mortality used for each city was the difference between the regression coefficients for the periods 1955–64 and 1964–70. The coefficients given for the latter period, after fluoridation in Birmingham, indicated a similar rate of change in all the cities. Those given for the earlier period, up to 1964, showed a relatively steady crude death rate in Birmingham between 1955 and 1964 and an increasing rate in the other cities. Use of the difference between the regression coefficients as an index of change thus gave a larger value for Birmingham than for the other cities, due almost entirely to an unusually steady mortality experience in Birmingham during the few years before fluoridation.

If the rates for individual years are examined instead of the average picture presented by the regression lines, and if data are analysed for a longer

*Held at Wembley, England, in July 1980 and sponsored by the International Society for Preventive Oncology, Inc.

period of years both before and after 1964 (that is, from 1951 to 1978), it is clear that there is nothing exceptional in the cancer mortality experience of Birmingham viewed in the context of the pattern of change in other large cities (see Figure). In all the cities there has been an increase, which is rapid at some periods and slow at others. The data used for the Figure were abstracted from the Registrar General's *Statistical Review of England and Wales* for the years 1951 to 1973, and from the OPCS *Mortality Statistics* for the years 1974 to 1978; the population estimates were provided by the OPCS for the years 1974 to 1978, except that, for the years 1961 to 1971, the Registrar General's *Revised Estimates of the Population of England and Wales*[6] were used instead of the yearly estimates published in the annual volumes of the *Statistical Review*. The revised estimates were prepared by the OPCS because, with the analysis of the 1971 national census, it became clear that, especially in the larger cities, changes in population size due to migration had been underestimated in the yearly estimates. In the cities examined in the Figure, the two estimates differ by as much as 5% for some years. Burk made use of the revised estimates for Birmingham and Manchester[3] but, for the other cities in his tabulations, the figures are those given in the annual volumes of the Registrar General's *Statistical Review*. This could account for some of the difference between Birmingham and other cities reported by Burk for the period before 1964.

It is clear from the Figure that there is considerable variation between individual years in the crude cancer death rate. It happened that the 1964 rate for Birmingham was below the rates for either 1963 or 1965 and Burk's inclusion of the 1964 rate in the regression analyses for both the pre-fluoridation and post-fluoridation periods[3] served to heighten his impression of an abrupt change in rate commencing in 1964. So also did his exclusion of the years 1953 and 1954 and the years 1971 to 1977 which had been included in his initial analysis of the data for Birmingham and Manchester.[2]

The Figure shows that there is nothing exceptional in the mortality experience of Birmingham when crude death rates are used as the index. They give, of course, no other information of value. As we showed elsewhere[4] they fail to distinguish genuine changes in rate from changes due to differential aging of the population, and they distort the relative ranking of the cities.

No data are available from which it would be possible to calculate age-standardised rates for individual years before 1971, but, in his latest presentation, Burk[3] has used a rough kind of age-standardisation for the years 1971 to 1977.

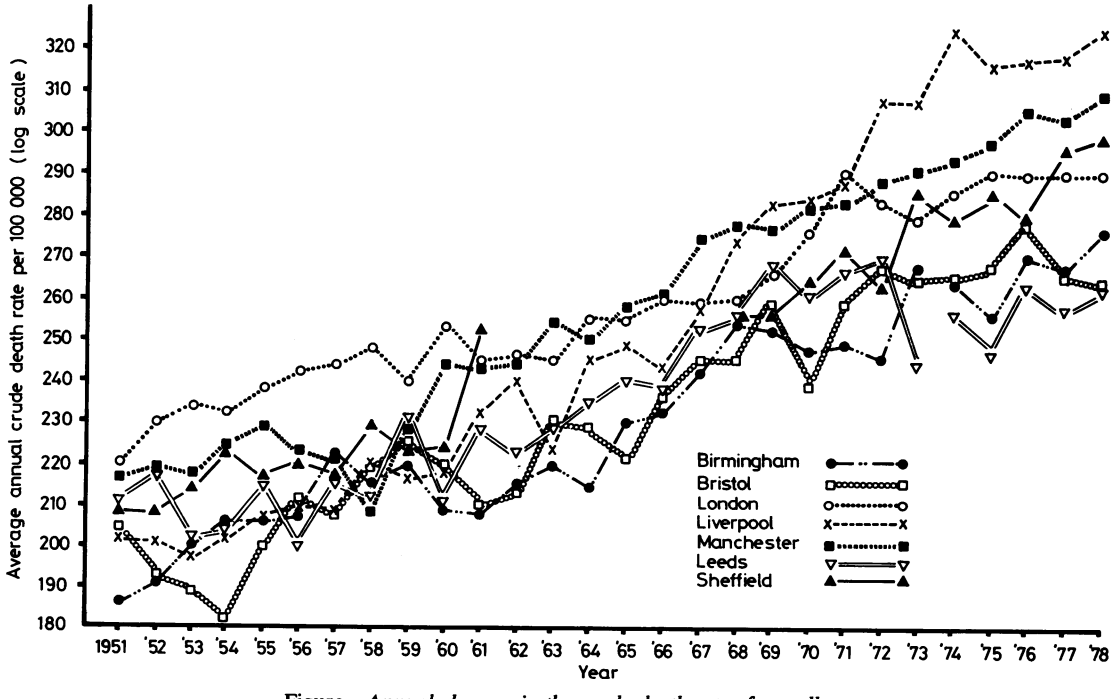

Figure *Annual changes in the crude death rates from all malignant neoplasms in the seven largest English cities*

Cancer deaths by age and sex and estimates of population by age and sex for individual years were obtained from the OPCS and age-specific rates were calculated for the broad age groups 0–14, 15–44, 45–64, 65–74, and 75 and over. Mean rates for each age-sex group were calculated from regression analyses of the annual age-specific rates against year of death, and the mean rates were applied to a standard population to obtain age-sex-standardised rates. The comparison of standardised rates was, however, restricted to the two cities of Birmingham and Manchester and, having selected Manchester for comparison, it is not surprising that a difference was found. The selection of Sheffield would have led to the finding of a difference in the opposite direction (see Cook-Mozaffari *et al*[4] for a detailed comparison of age-standardised rates).

DATA FOR OTHER FLUORIDATED AREAS

England and Wales

Difficulties face anyone examining cancer mortality in relation to fluoridation within the United Kingdom because only four communities, Anglesey, Watford, Birmingham, and Solihull, have had fluoridated water supplies long enough for any effect that might be produced to become apparent (Watford and Anglesey from the mid-'fifties and Birmingham and Solihull from the mid-'sixties). Kinlen, Clarke, and

Table 2 *Standardised mortality ratios (SMRs) and observed numbers of deaths from cancer in Birmingham and Solihull and in the non-fluoridated parts of the West Midlands Conurbation*

	SMR (no. of deaths in brackets)*			
	Birmingham	*Solihull*	*Birmingham and Solihull*	*Rest of the West Midlands Conurbation*
1959–1963	106·26 (11 727)	97·18 (828)	105·61 (12 555)	98·37 (10 753)
1969–1973	113·28 (12 810)[a]	99·35 (1053)	112·09 (13 863)[d]	107·24 (13 787)
1969–1973	112·15 (13 635)[b]		111·12 (14 688)[e]	107·88 (10 881)[f]
1974–1978**	113·27 (14 059)	101·50 (1225)[c]	112·22 (15 284)	106·48 (12 226)[f]
% change 1959–1963 to 1969–1973	+6·6	+2·2	+6·1	+9·0
% change 1969–1973 to 1974–1978	+1·0	+2·2	+1·0	−1·3
% change 1959–1963 to 1974–1978	+6·6	+4·4	+6·3	+8·2

*SMRs were calculated from expected values derived from the combined 1959–63 and 1969–73 age-specific rates for England and Wales (see Cook-Mozaffari, Bulusu, and Doll[4]). There are slight differences between the figures for Birmingham shown in this table and those presented by Cook-Mozaffari *et al* because, in keeping with the methods followed by Kinlen *et al*,[7] age-specific rates up to the age of 75 and over were used, rather than those up to 85 and over, and the observed and expected rates for men and women were summed before the calculation of the SMRs, whereas Cook-Mozaffari *et al* used the average of the male and female SMRs to estimate the combined rate for both sexes.

**Estimated populations for 1976 were provided by the OPCS, as were the number of deaths from 1974–8 for the area that was Warley county borough (CB) before April 1974. The population for Warley CB in 1976 was estimated from the population of Sandwell metropolitan district (MD), taking the proportion in each age-sex group represented by Warley CB as a part of Sandwell MD at the time of the 1971 national census.

[a]Figures for the Birmingham CB
[b]Figures for Birmingham CB plus Sutton Coldfield metropolitan borough (MB) incorporated into Birmingham MD in 1974
[c]Figures for the area that was Solihull CB before April 1974 (provided by the OPCS). Population estimated from the population of Solihull MD in 1976, taking the proportion in each age-sex group represented by Solihull CB as a part of Solihull MD at the time of the 1971 national census
[d]Figures for Birmingham CB plus Solihull CB
[e]Figures for Birmingham CB plus Solihull CB plus Sutton Coldfield MB (see note b)
[f]Figures for the remainder of the West Midlands Conurbation excluding Warley CB (or its equivalent after April 1974)

Doll[7] compared cancer mortality trends between 1959–63 and 1969–73 in the combined Birmingham-Solihull areas with those in the rest of the West Midlands Conurbation and found an increase of 6·1% in Birmingham-Solihull compared with an increase of 9·0% in the rest of the West Midlands Conurbation. This comparison has been extended to cover the period 1974–8 (Table 2).

The data for Anglesey have recently been examined (Wynne Griffith, personal communication, 1980). These showed an increase in cancer mortality between 1949–53 and 1959–63 of 11·1% and a decrease between 1959–63 and 1969–73 of 8·0% (Table 3). If cancers of the lung and bronchus are removed from the total, the increase for other malignant neoplasms between 1949–53 and 1959–63 is only 1·8%, while the decrease between the latter two periods is 16·7%.

United States of America

Fluoridation was started in the USA on a large scale in the early 1950s. By 1970, more than 80 million people in almost 5000 communities were receiving fluoridated water and claims have been made that fluoridation was followed by an increase in cancer mortality.[4] A large-scale check on changing death rates from cancer was subsequently made by Hoover *et al*[8] who compared cancer mortality in some 52 counties, where at least two-thirds of the communities were provided with fluoridated water between 1950 and 1964, with the situation in 157 control counties where no communities received fluoridated water until after 1970. All but one of the fluoridated counties had at least two-thirds of their populations in urban communities and only control counties with a similar degree of urbanisation were included in the survey. No attempt was made to exclude, from either the exposed or the control group, communities with naturally fluoridated water supplies, because the authors' previous study (ibid) and work in England[9] had indicated no effect of natural fluoridation on cancer risk.

Table 3 *Standardised mortality ratios (SMRs) and observed numbers of deaths from cancer in the county of Anglesey for the periods 1949–53, 1959–63 and 1969–73*

		SMR* (no. of deaths in brackets)		
		1949–53	*1959–63*	*1969–73*
All malignant neoplasms	Men	84 (299)	92 (332)	88 (355)
	Women	99 (266)	109 (322)	98 (325)
	Persons	90 (565)	100 (654)	92 (680)
Cancer of the trachea, bronchus, and lung	Men	29 (39)	66 (89)	90 (137)
	Women	35 (10)	29 (9)	69 (24)
	Persons	30 (49)	59 (98)	86(161)
All other malignant neoplasms	Men	117 (260)	108 (243)	87 (218)
	Women	106 (256)	119 (313)	101 (301)
	Persons	112 (516)	114 (556)	95 (519)

*Expected values for the calculation of the SMRs were derived from the age-specific rates for England and Wales for 1971.

Mortality data by age and sex were available from 1950 to 1969 for each county,[8] and age-standardised death rates were calculated for five-year periods (pentads) for counties grouped according to their date of fluoridation. It was thus possible to compare death rates for fluoridated and non-fluoridated areas from 10 years before fluoridation, for some groups of counties, up to 15 years after its introduction for others. Standardised mortality ratios (SMRs) were also calculated for each pentad using the age-specific rates of the relevant control counties to give expected values. (The 'pentad of fluoridation', for example, had an SMR derived from the pooled 'observed' and 'expected' cancer deaths for 1950–54, 1955–59, and 1960–64. The SMR for the pentad '15 years after fluoridation' was calculated simply for the period 1965–69 for those counties fluoridated in 1950–54). The SMRs for 34 individual types of cancer by sex were also examined in addition to the general cancer death rate for all sites. Further analyses of a similar kind were made for those counties where over 80% of the communities (containing on average 95% of the population) were provided with fluoridated water between 1950 and 1959. This comprehensive study gave no indication that the addition of fluoride to the water supplies had given any increased risk of dying from cancer up to 15 years after its introduction.

A subsequent survey[10] compared mortality trends between 1949–50 and 1969–71 in average age-sex-race-standardised mortality ratios in 227 cities of the USA which had been provided with fluoridated water supplies between 1945 and 1969, and in 187 cities with low natural fluoride in their water supplies. A 'regression to the mean'* effect was clearly apparent in this study and adjustment was made to allow for this effect. Comparison of the adjusted SMRs for cancer showed that they had increased on average by 8% in both the fluoridated and the non-fluoridated cities between the 1950 and 1970 periods.

A geographical study has also been made in the USA[11] comparing the 1969–71 mortality levels from a variety of causes (including 'all cancer' and seven individual types of cancer) in 24 cities fluoridated before 1960 and in 22 non-fluoridated cities, all with a population of more than 250 000. The problem, that in geographical comparisons differences observed could have been present before the

*Whereby those cities with the lowest and highest initial death rates showed on average the largest and the least change in rates over the study period.

introduction of the suspected noxious agent, was tackled in this survey by adjustment for a number of social, demographic, and economic variables which commonly show association with mortality levels. The average age-race-sex-adjusted death rates for all cancer and for the individual sites (before adjustment for the demographic and socioeconomic factors) were for the most part higher in the fluoridated than in the non-fluoridated cities. Adjustment for these factors gave rates that were virtually identical in the two sets of cities.

Australia

A study from Australia[12] has compared the 1970–72 age-standardised mortality ratios for all cancers in 10 localities where the water supplies were fluoridated between 1956 and 1967 with those in 19 non-fluoridated localities of similar population size. The pooled age-sex-standardised mortality ratio for all cancer was lower in the fluoridated (91·6) than in the non-fluoridated localities (94·9). The study is limited by the fact that the total population receiving fluoridated water was only about 164 000. Moreover, little can be deduced from the post-fluoridation figures without knowledge of the death rates experienced before its introduction or, if these are not available, without adjustments of the kind made in the American geographical study carried out by Erickson.[11]

New Zealand

Fluoridation of water supplies of some towns was introduced in New Zealand in 1954, and by 1975 about 54% of the total population were receiving fluoridated water. A recently completed study[13] has compared the cancer mortality rates for 1961 and 1976 for a group of urban areas which were fluoridated between 1965 and 1967 and for a group of unfluoridated urban areas. Comparisons of death rates have been limited to the population aged 45 and over, since 90% of cancer deaths occurred in this age group. Comparisons have been made for both sexes, for 10-year age groups up to 85 and over, and for the total population aged 45 and over. The latter, which are in effect crude death rates, showed for men an increase of 10% in the fluoridated areas between 1961 and 1976 and an increase of 29% in the unfluoridated areas. For women there was a decrease of 5% in the fluoridated areas and an increase of 2% in the non-fluoridated areas. If the age-specific rates are used to calculate age-standardised rates for the population aged 45 and over, these percentage changes are relatively unaltered (far less than would have occurred if crude rates had been calculated using the total all-age populations). Using the age-standardised rates, there was an increase of 12% for men in the fluoridated areas and of 30% in the unfluoridated areas. For women there was a decrease of 9·1% in the fluoridated areas and of 2% in the non-fluoridated areas.

Conclusions

Claims that unusual increases in cancer mortality have occurred in England after fluoridation have been examined and have been shown to rest on incorrect arithmetic, on the use of inappropriate statistical methods, and on examination of too restricted a part of the available data.

Studies from other parts of the world which have examined trends in cancer mortality after fluoridation, or which have made geographical comparisons between fluoridated and unfluoridated areas, have been reviewed. There is no evidence either from England and Wales or from elsewhere in the world that the addition of fluoride to water supplies has increased the risk of dying from cancer.

Reprints from Ms. P. Cook-Mozaffari, Medical Research Council External Staff, Department of Community Medicine and General Practice, University of Oxford, Oxford OX1 3QG.

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